

Inside: Synthetic biology—Engineering nature to make materials

MRS Bulletin

July 2018 Vol. 43 No. 7
www.mrs.org/bulletin

MRS MATERIALS RESEARCH SOCIETY®
Advancing materials. Improving the quality of life.

Ultrafast imaging of materials dynamics

ALSO IN THIS ISSUE

Halide perovskite photovoltaics:
History, progress, and perspectives

Quantum materials for brain sciences
and artificial intelligence

CAMBRIDGE
UNIVERSITY PRESS

CUSTOMIZED PRODUCTION ION IMPLANTERS



- Beam energies from 10 keV up to several 10s of MeV
- Beam currents from 100 micro-amps up to several milliamps
- Ion species, including H, He, B, P, As and others
- Single wafer or batch processing of wafers up to and including 300 mm
- In-air or in-vacuum cassette-to-cassette wafer handling
- Electrostatic and/or mechanical wafer clamping



High Voltage Engineering

High Voltage Engineering Europa B.V.

P.O. Box 99, 3800 AB Amersfoort, The Netherlands

Tel: 31 33 4619741 • info@highvolteng.com

www.highvolteng.com

Calling Early-Stage Materials Innovators!

Showcase your technology... Connect with investors & industry professionals

iMatSci Innovation Showcase



2018 **MRS**® FALL MEETING & EXHIBIT

Hynes Convention Center | Boston, Massachusetts

Tuesday, November 27 – Wednesday, November 28

Are you a pre-revenue or seed-stage materials innovator and entrepreneur looking to demonstrate the value of your product to high-level decision makers and materials venture investors? If so, join us for the **iMatSci Innovation Showcase**, where you will have the unprecedented opportunity to meet and interact with industry, R&D leaders, and investors who can help to effectively lead your venture to success!

Past participants include Advanced Research Projects Agency–Energy, Air Force Office of Scientific Research, BASF Ventures, The Dow Chemical Company, Lockheed Martin, MilliporeSigma, Samsung Research America, Solvay Ventures, and more!

Interested in being a part of iMatSci this year?

Submission Site Opens: June 1, 2018

www.mrs.org/become-an-innovator

Why Get Involved?

Each innovator will be provided with exhibit space at the Hynes Convention Center to present his/her technology or product using various forms of media such as pitch decks, marketing videos, prototypes and executive summaries. Presentations will be judged by experienced technology investors and industry professionals.

By participating in iMatSci, innovators will be granted access to:

- **A full schedule of workshops, seminars and panel discussions**, with topics specifically geared toward the success of early-stage innovators
- **One-on-one meeting spaces** to showcase their innovations and interact with strategic partners, industry technology scouts, investors and collaborators
- **Exclusive networking events**, Q&A sessions and receptions
- **An opportunity to network and be paired with mentors** from industry, local accelerators and investors
- **Cash prizes awarded** to the top three most innovative teams and a **\$10,000 investment from the Chemical Angel Network** most likely in the form of a convertible note.

“My experience at iMatSci was invaluable. Few opportunities can match what iMatSci provides by allowing innovators to meet with other entrepreneurs to discuss their technology, pathways for funding, and strategies for commercialization. It was a richly stimulating experience.”

– C. Wyatt Shields IV, *iMatSci* Innovator, Encapsio LLC;
Research Triangle MRSEC Fellow

How to Participate

To participate, innovators should be:

- Interested in commercializing their technologies
- Able to propose a value proposition for their innovations
- Capable of effectively demonstrating the commercial applications of their technologies
- Actively seeking partners, funding and/or paths for commercialization

Online applications will be accepted through **August 1, 2018**, and must be submitted through the iMatSci submission portal at <https://imatsci.mrs.org>.

For further information about the submission guidelines, innovators packages, selection criteria, sponsorship opportunities and more, check out the complete iMatSci web page at www.mrs.org/imatsci.

For questions about iMatSci or to become a sponsor, please contact:

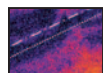
Natalie Larocco
Materials Research Society
larocco@mrs.org
imatsci@mrs.org
724.779.2744

MRS Innovation **Connexions**
Connecting People and Ideas

www.mrs.org/imatsci

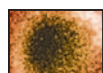
CONTENTS

ULTRAFAST IMAGING OF MATERIALS DYNAMICS



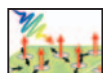
485 Atomic-scale imaging of ultrafast materials dynamics

David J. Flannigan and Aaron M. Lindenberg,
Guest Editors



491 Scanning ultrafast electron microscopy: Four-dimensional imaging of materials dynamics in space and time

Ding-Shyue Yang, Bolin Liao, and Omar F. Mohammed



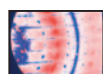
497 Ultrafast electron energy-loss spectroscopy in transmission electron microscopy

Enrico Pomarico, Ye-Jin Kim,
F. Javier García de Abajo, Oh-Hoon Kwon,
Fabrizio Carbone, and Renske M. van der Veen



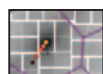
504 Structural dynamics probed by high-coherence electron pulses

Armin Feist, Gero Storeck, Sascha Schäfer, and
Claus Ropers



512 Ultrafast switching in an atomic wire system at surfaces

Michael Horn-von Hoegen



520 Ultrafast Fourier transform inelastic x-ray scattering

Mariano Trigo

TECHNICAL FEATURE



527 Halide perovskite photovoltaics: History, progress, and perspectives

Symposium X (Frontiers of Materials Research)
presentation given at the 2017 MRS Fall Meeting
Nam-Gyu Park

TECHNICAL FEATURE



534 Quantum materials for brain sciences and artificial intelligence

Shriram Ramanathan



ON THE COVER

Ultrafast imaging of materials dynamics.

The advent of short-pulse electron and x-ray sources has enabled pump-probe approaches for elucidating ultrafast materials dynamics. This issue of *MRS Bulletin* provides a cross section of the vigorous activity occurring in the study of light-induced ultrafast materials dynamics as it relates to various approaches. The cover shows measurements of the center of mass of the scattered x-ray spot in a

pump-probe geometry that reveal an unexpected electronically induced compression appearing at time $t = 10$ ps, associated with a light-induced modulation of the van der Waals interaction. Credit: Ehren Mannebach, Stanford University PULSE Institute. See the technical theme that begins on page 485.

DEPARTMENTS



OPINION

- 469 **Letter from the President**
Advocating on behalf of the materials research community
Sean J. Hearne
- 471 **Editorial**
Calling all postdocs ...
Gopal R. Rao



NEWS & ANALYSIS

- 472 **Materials News**
- **Multiscale modeling speedily predicts fatigue failure in hip implants**
Hortense Le Ferrand
 - **Molecular bridging agents render ultra-tough macroscopic graphene films**
Tianyu Liu
 - **Energy profile flattened to enhance piezoelectricity in ceramics**
Abby Goldman
- 475 **Science Policy**
- **US Department of Defense funds high-risk innovative materials research**
William G. Schulz
 - **Canada-UK Advanced Manufacturing Partnering Mission identifies collaboration opportunities**
- 477 **Feature Article**
**Synthetic biology—
Engineering nature to make materials**
Philip Ball



DIVERSITY IN MS&E

- 541 **Strengthening diversity and cooperation through international collaborations: A focus on Africa, South America, and the Caribbean**
Wole Soboyejo
Feature Editor: Lynnette D. Madsen



SOCIETY NEWS

- 548
- **2018 MRS Spring Meeting features materials developments across disciplines**
 - **In memoriam: Lasar Simhovich Shvindlerman**
Eugen Rabkin
 - **Materials Research Society seeks award nominations**
- 554
- **MRS Communications Abstracts**



FEATURES

- 556 **Book Reviews**
- **Graphene for Defense and Security**
Andre U. Sokolnikov
Reviewed by Aurelia Meghea
 - **Imperfections in Crystalline Solids**
Wei Cai and William D. Nix
Reviewed by Sanjay Mathur
 - **What Every Postdoc Needs to Know**
Liz Elvidge, Emma Williams, and Carol Spencely
Reviewed by Protima Rauwel
- 559 **Postterminaries**
Striving for a low-waste lifestyle
Steve Moss



CAREER CENTRAL

ADVERTISERS IN THIS ISSUE

Page No.

American Elements	Outside back cover
High Voltage Engineering	Inside front cover
MilliporeSigma (Sigma-Aldrich Materials Science).....	Inside back cover
National Electrostatics Corp.	490

www.mrs.org/bulletin

www.mrs.org/energy-quarterly

www.mrs.org/mymrs

<http://journals.cambridge.org>

mrsbulletin-rss

[@mrsbulletin](https://twitter.com/mrsbulletin)

About the Materials Research Society

The Materials Research Society (MRS), a not-for-profit scientific association founded in 1973 and headquartered in Warrendale, Pennsylvania, USA, promotes interdisciplinary materials research. Today, MRS is a growing, vibrant, member-driven organization of over 16,000 materials researchers spanning over 80 countries, from academia, industry, and government, and a recognized leader in the advancement of interdisciplinary materials research.

The Society's interdisciplinary approach differs from that of single-discipline professional societies because it promotes information exchange across many scientific and technical fields touching materials development. MRS conducts three major international annual meetings and also sponsors numerous single-topic scientific meetings. The Society recognizes professional and technical excellence and fosters technical interaction through University Chapters. In the international arena, MRS implements bilateral projects with partner organizations to benefit the worldwide materials community. The Materials Research Society Foundation helps the Society advance its mission by supporting various projects and initiatives.

2018 MRS BOARD OF DIRECTORS

President Sean J. Hearne, Sandia National Laboratories, USA

Immediate Past President Susan Trolier-McKinstry,

The Pennsylvania State University, USA

Vice President and President-Elect Michael R. Fitzsimmons,

Oak Ridge National Laboratory and The University of Tennessee, USA

Secretary Eric A. Stach, University of Pennsylvania, USA

Treasurer David J. Parrillo, The Dow Chemical Company, USA

Executive Director Todd M. Osman, Materials Research Society, USA

Griselda Bonilla, IBM T.J. Watson Research Center, USA

Li-Chyong Chen, National Taiwan University, Taiwan

Matt Copel, IBM T.J. Watson Research Center, USA

Paul S. Drzaic, Apple, Inc., USA

Dawnielle Farrar-Gaines, Johns Hopkins University, USA

Yury Gogotsi, Drexel University, USA

Claudia Gutiérrez-Wing, Instituto Nacional de Investigaciones Nucleares, Mexico

Young-Chang Joo, Seoul National University, South Korea

Lincoln J. Lauhon, Northwestern University, USA

Paul C. McIntyre, Stanford University, USA

Christopher A. Schuh, Massachusetts Institute of Technology, USA

Rachel A. Segalman, University of California, Santa Barbara, USA

Magaly Spector, The University of Texas at Dallas, USA

Molly M. Stevens, Imperial College London, UK

Ehrenfried Zschech, Fraunhofer Institute for Ceramic Technologies and Systems, Germany

MRS OPERATING COMMITTEE CHAIRS

Academic Affairs Bruce M. Clemens, Stanford University, USA

Awards Albert Polman, FOM Institute AMOLF, The Netherlands

Government Affairs David P. Norton, University of Florida, USA

Meetings Terry Aselage, Sandia National Laboratories, USA

Member Engagement Sossina M. Haile, Northwestern University, USA

Public Outreach Elizabeth Kuppp, The Pennsylvania State University, USA

Publications Shefford P. Baker, Cornell University, USA

MRS HEADQUARTERS

Todd M. Osman, Executive Director

J. Ardie Dillen, Director of Finance and Administration

Damon Dozier, Director of Government Affairs

Patricia Hastings, Director of Meetings Activities

Eileen M. Kiley, Director of Communications

Editor

Gopal R. Rao, rao@mrs.org

Managing Editor

Lori A. Wilson, lwilson@mrs.org

News Editor

Judy Meiksin, meiksin@mrs.org

Technical Editor

Lisa C. Oldham, oldham@mrs.org

Editorial Assistants

Michelle S. Raley, raley@mrs.org

Mary Wilmoth

Associate Technical Editor

Carol Tseng

Production/Design

Michael P. Moran, Rebecca Tokarczyk, Felicia Turano, and TNQ

Associate Production Editor

Katie Wurtzel

Principal Development Editor

Elizabeth L. Fleischer

Director of Communications

Eileen M. Kiley

Guest Editors

David J. Flannigan and

Aaron M. Lindenbergh

Special Consultant

Angelika Veziridis

Energy Quarterly

Andrea Ambrosini (Chair), Monika Backhaus, Kristen Brown, David Cahen, Russell R. Chianelli, George Crabtree, Elizabeth A. Köcs, Shirley Meng, Sabrina Sartori, Anke Weidenkaff, M. Stanley Whittingham, and Steve M. Yalisove

Advertising/Sponsorship

Mary E. Kaufold, kaufold@mrs.org
Donna L. Watterson, watterson@mrs.org

Member Subscriptions

Michelle Judt, judt@mrs.org

Non-Member Subscriptions
subscriptions_newyork@cambridge.org

EDITORIAL BOARD

Fiona C. Meldrum (Chair), University of Leeds, UK

Ilke Arslan, Pacific Northwest National Laboratory, USA

V.S. Arunachalam, Center for Study of Science, Technology & Policy, India

N. (Balu) Balasubramaniam, Bangalore, India (retired)

Christopher J. Bettinger, Carnegie Mellon University, USA

Tommie Kelley, 3M, USA

Igor Lubomirsky, Weizmann Institute, Israel

Amit Misra, University of Michigan, USA

Steven C. Moss, The Aerospace Corporation, USA (retired)

Julie A. Nucci, Cornell University, USA

Linda J. Olafsen, Baylor University, USA

Boaz Pokroy, Technion-Israel Institute of Technology, Israel

Zhiwei Shan, Xi'an Jiaotong University and Hysitron, China

James W. Stasiak, HP Inc., USA

Carol Trager-Cowan, University of Strathclyde, UK

Eric Werwa, Washington, DC, USA

M. Stanley Whittingham, Binghamton University, The State University of New York, USA

Steve M. Yalisove, University of Michigan, USA

VOLUME ORGANIZERS

2018 **Karsten Albe**, Technische Universität Darmstadt, Germany

Hiroshi Funakubo, Tokyo Institute of Technology, Japan

Michael Hickner, The Pennsylvania State University, USA

Bethanie Stadler, University of Minnesota, USA

2019 **Craig B. Arnold**, Princeton University, USA

Claus Daniel, Oak Ridge National Laboratory and The University of Tennessee, Knoxville, USA

Seung Min Han, Korea Advanced Institute of Science and Technology, Republic of Korea

Gabriel Montaño, Los Alamos National Laboratory/Northern Arizona University, USA

2020 **Hongyou Fan**, Sandia National Laboratories, USA

Oleg Gang, Brookhaven National Laboratory, USA

Seokwoo Jeon, Korea Advanced Institute of Science and Technology, Republic of Korea

Tae-Woo Lee, Seoul National University, South Korea

MRS Bulletin (ISSN: 0883-7694, print; ISSN 1938-1425, online) is published monthly by the Materials Research Society, 506 Keystone Drive, Warrendale, PA 15086-7573. © 2018 Materials Research Society. Permission required to reproduce content. Periodical postage paid at New York, NY, and at additional mailing offices. POSTMASTER: Send address changes to *MRS Bulletin* in care of the Journals Department, Cambridge University Press, 100 Brook Hill Drive, West Nyack, NY 10994-2113, USA. Printed in the U.S.A.

Membership in MRS is \$130 annually for regular members, \$32 for students, and includes an electronic subscription to *MRS Bulletin*. Print subscriptions are available to MRS members for an additional \$25. Individual member subscriptions are for personal use only. Non-member subscription rates are \$560 (USD) for one calendar year (12 issues). Requests from subscribers for missing journal issues will be honored without charge only if received within six months of the issue's actual date of publication.

MRS Bulletin is included in Current Contents®/Engineering, Computing, and Technology; Current Contents®/Physical, Chemical, and Earth Sciences, the SciSearch® online database, Research Alert®, Science Citation Index®, and the Materials Science Citation Index™. Back volumes of *MRS Bulletin* are available on microfiche through University Microfilms Inc., 300 North Zeeb Road, Ann Arbor, MI 48106, USA.

Authors of each technical article appearing in *MRS Bulletin* are solely responsible for all content in their article(s), including accuracy of the facts, statements, and citing resources. Facts and opinions are solely the personal statements of the respective authors and do not necessarily represent the views of the editors, the Materials Research Society, or Cambridge University Press.

Send Letters
to the Editor to
Bulletin@mrs.org.
Include your name,
affiliation, and full
contact information.